Amendments to the Specification

Please replace the paragraph 3 beginning on line 8 of page 2 with the following amended paragraph:

According to an aspect ~~of the present invention, the above object may be achieved by a method as set forth in claim 1, where~~ an image of an object is reconstructed from volumetric data of the object. The volumetric data include a plurality of projections corresponding to a plurality of time points. According to the method of this exemplary embodiment, a motion of the object is estimated. Then, first time points are determined, where the motion of the object is minimal on the basis of the estimated motion and projections are selected from the plurality of projections on the basis of these first time points. Then, the image is reconstructed from the projections selected from the plurality of projections.

Please replace the paragraph 5 beginning on line 23 of page 2 with the following amended paragraph:

According to another exemplary embodiment ~~of the present invention as set forth in claim 2~~, the volumetric data correspond to cardiac CT data and simultaneously measured electrocardiogram (ECG) data or photoplethysmographic (PPG) data. According to this exemplary embodiment of the present invention, a reconstruction of a series of low resolution 3D images of the heart is performed, which cover the cardiac cycle, i.e. a series with different phase points. Then, the determination of the motion fields is performed for the series of low resolution 3D images. Such motion fields then describe the cyclic motion of the heart with a low spatial resolution. Then, time periods are determined from the motion fields at which selected areas of the heart are addressed. These time points are collected in a temporal map, which then contains optimal time points for each of the selected regions of the heart. Then, on the basis of this high temporal map, a high resolution image is reconstructed from projections corresponding to the time points of minimal motion in the high temporal map.

Please replace the paragraph 3 beginning on line 8 of page 3 with the following amended paragraph:

According to another exemplary embodiment~~ of the present invention as set forth in claim 3~~, the missing time points in the high resolution map are determined by interpolation. Furthermore, according to this exemplary embodiment of the present invention, a reconstruction of the high resolution image is performed, such that data gathered at a certain time point are used to reconstruct a first region of the heart, whereas data corresponding to another time point are used for reconstructing a second region of the heart.

Please replace the paragraph 5 beginning on line 19 of page 3 with the following amended paragraph:

According to another exemplary embodiment~~ of the present invention as set forth in claim 4~~, the volumetric data correspond to the coronary artery region and simultaneously measured electrocardiogram data. Furthermore, according to this exemplary embodiment of the present invention, the image is reconstructed on the basis of an iterative reconstruction optimization.

Please replace the paragraph 7 beginning on line 27 of page 3 with the following amended paragraph:

According to another exemplary embodiment~~ of the present invention as set forth in claim 5~~, the selection of the projections from the plurality of projections corresponds to a setting of a gating window. A variation of the gating window causes a reconstruction of a new image on the basis of the iterative reconstruction optimization in real-time. This image may then be displayed on a display. According to an aspect of this exemplary embodiment of the present invention, a gating window adaptation with respect to width and position is performed based on the motion fields, such that, e.g. each of the coronary vessels having different motion patterns throughout the cardiac cycle is reconstructed from data corresponding to its own individual point in time (or phase point of the ECG signal), where its speed of motion is minimal. This means that, according to this exemplary embodiment of the present invention, the reconstruction window or gating window is shifted to the minimum motion (rest) phase for a particular vessel section of interest, in order to achieve optimum image quality.

Please replace the paragraph 2 beginning on line 8 of page 4 with the following amended paragraph:

According to another exemplary ~~embodiment of the present invention as set forth in claim 6~~, the variation of the gating window is performed on the basis of the motion fields or the magnitude of the motion, such that the gating window is automatically set to time points, where there is minimal motion in the object, such that the new image is automatically optimized.

Please replace the paragraph 4 beginning on line 15 of page 4 with the following amended paragraph:

According to another exemplary ~~embodiment of the present invention as set forth in claim 7~~, the variation of the gating window is based on an input by, for example, an operator, such that a real-time interactive optimization of the image is provided. In other words, an image determined on a first gating window may be displayed to a user. Then, this window may be manipulated by the user in terms of position and width, using, for example, standard level or window mechanisms. Then, according to an aspect of this exemplary embodiment of the present invention, the reconstruction result is immediately updated, such that the user may interactively control the optimization process.

Please replace the paragraph 5 beginning on line 24 of page 4 with the following amended paragraph:

According to another exemplary embodiment ~~of the present invention as set forth in claim 8~~, a segmentation of the coronary vessel tree is performed from the volumetric data, allowing for an image displaying the coronary vessel tree without disturbing neighboring areas.

Please replace the paragraph 6 beginning on line 28 of page 4 with the following amended paragraph:

According to an exemplary embodiment ~~of the present invention as set forth in claim 9~~, an image processing device is provided, allowing for an improved imaging of moving or deforming objects on the basis of a determination of time points with a minimal motion and the

reconstruction of the image on the basis of projections of the volumetric data corresponding to these time points.

Please replace the paragraph 1 beginning on line 1 of page 5 with the following amended paragraph:

~~Claims 10 and 11 provide further~~ Further exemplary embodiments of the image processing device are also discussed~~according to the present invention~~.

Please add the following paragraphs beginning on line 17 of page 14:

As noted above, the motion fields may be determined as described in T. Schäffter et al., "Motion compensated projection reconstruction" Magn. Reson. Imaging, 41:954 – 963, 1999. As discussed in the subject reference, motion during the acquisition of data degrades the image quality by introducing artifacts. In radial acquisition schemes, motion leads to blurring. If the acquisition of one data subset is fast with respect to the motion, all objects in the excited slice can be regarded as fixed during the acquisition of one data subset and motion occurs only between the acquisition of successive subsets. In reality this assumption is only approximately fulfilled, so that motion during the acquisition of a subset still causes a residual blurring of the sub-image, which reflects the mean motion state of the acquisition period. A high-resolution image is the sum of the subset images, with each subset image representing a different motion state. Simply adding these subset images would lead to a superposition of the different motion states, and can thus to blurring artifacts. Motion can be estimated from the sequence of low-resolution images, and can then be compensated before the sub-images are combined into a high-resolution image.

The measurement of projections is the simplest form of a navigator that allows detection of translations. Recently the use of more sophisticated navigators has been proposed. The acquisition of a number of different projections can be used to detect more complex motion. For example, the motion of two rigid bodies that move in different directions can be detected by two orthogonal projections. If the motion becomes more complex, other methods are adequate. The interleaved radial acquisition scheme allows reconstructing low-resolution images from each data subset. Assuming that each subset corresponds to one motion state, motion can be estimated

using the low resolution images. To that end, so called block-matching techniques are applied. These techniques are based on the assumption of "optical flow" i.e. brightness changes in an image are caused only by the object's movement. Following this principal, motion is estimated by optimally matching the gray value patterns of rectangular regions of interest, "the blocks", between two images, and the mutual displacement of the block center is assigned to the motion estimate. The methods most widely used for estimating the block similarity are based on gray value differences, e.g. mean squared differences, or on gray value correlation. The cross correlation function can be used to identify the most similar block positions because it allows a better definition of the similarity maximum in comparison with difference-based measures. The latter, however, allow for more precise location of the optimal block positions. The difference in the respective block positions directly give the displacement d(x) if the imaged object part.

A number of block matching algorithms have been proposed that use different search strategies. The computational cost of the algorithms depends strongly on the size of the blocks and the search area. In the simplest form, only displacements within the search area can be detected. The computational cost for a full search grows with the square of the size of the size of the search area. This makes a full search slow when large displacements are to be detected. The performance of the block matching algorithm can be involved by use of a hierarchical approach. Whenever movements of structures results in spatially smooth displacement fields, these can be reliably estimated even under unfavorable signal-to-noise conditions by hierarchical block matching using sets of images of increasing spatial resolution. Starting from the lowest-resolution level, motion estimates are progressively refined by taking the displacement obtained at one level as the starting position for a local optimization at the next finer level that gives a more accurate update. This bottom-up-refinement ends at the original resolution level and provides a full-resolution displacement estimate. This approach is very fast, due to the reduction in geometric scale, it only involves small search areas and block sizes for detecting even large displacements. The search range of a hierarchical block matching algorithm using a search range *SR* on each of the *L* levels is approximately given by

Equation 1:

$$SR_{HR}=SR\cdot 2^{L-1}$$

due to the fact that the largest displacements should be determined on the lowest resolution level and the search on the intermediate and on the original resolution level are used for correction and refinement, only. The use of different resolution makes the hierarchical search very efficient. For a lower resolution level the number of blocks is decreased by a factor of 4 by interpolation in both image dimensions. Assuming that identical search strategies are applied to all resolution levels, i.e. the block size search ranges and the block overlaps are identical, the overall complexity of a hierarchical search can be estimated as:

Equation 2:

$$\mathrm{Comp(HR)} = \mathrm{SR}^2 * \sum_{l=0}^{L-1} \left(\frac{1}{4}\right)^{l} * \mathrm{Comp(SIM)}$$

where Comp(Sim) denotes the complexity of the similarity measures for a given block size. The number of resolution levels L and the search range SR depends on the length of the largest displacement vector that has to be detected.

The hierarchical search produces smooth displacement fields reflecting true physical movements. It is robust against noise and motion artifacts since only the largest and best-defined object structures survive on the lowest resolution level where the estimation starts. The displacement vectors determined on the low-resolution scale are replicated to provide a displacement field for the search on the next scale. The replication of the displacement vectors inside one block can lead to vectors in noisy background that are not related to real motion. However, no problems will arise from this fact because only blocks containing noise are matched against each other and thus only the noise structure would change locally.

The accuracy of the hierarchical block matching algorithm can be further improved by the use of strongly overlapping blocks. The distance between the block-centers is then smaller than the block sizes. However, the limit of this idea is to perform block matching for each pixel. The motion estimation technique has been applied to the acquired sub-images as described in the previous sections. Motion is estimated with respect to the second subset used as a reference state of motion. However, the reference frame can be chosen arbitrarily, and motion can be estimated with respect to each of the four motion states. After determining all displacement fields $\vec{d}_i(\vec{x})$,

the reconstruction of the high-resolution image according to can simply be modified to compensate for motion:

Equation 3:

$$I_{MC}^{HH}(\vec{x}) = \sum_i BP\left(\left\{p_\theta\left(\vec{u}_\theta * \left(\vec{x} + \vec{d}_i(\vec{x})\right)\right)\right\}_i\right)$$

$$\vec{u}_\theta = (\cos\theta, \sin\theta).$$

In this equation, a back-projection is applied to the filtered projection p_θ of the *i*th subset taking the displacement $\vec{d}_i(\vec{x})$ of each pixel with respect to one reference frame into account i.e. the back-projection is calculated at the position $\vec{x} + \vec{d}_i(\vec{x})$. The motion compensated (MC) high-resolution image $I_{MC}^{HH}(\vec{x})$ represents the motion state with respect to one reference frame. As described above, the reference frame can be chosen arbitrarily and for each subset a high-resolution MC-image can be reconstructed using different sets of displacement fields. Thus the MC images show different motion states with high spatial resolution.

According to Equation 3, an MC-image is reconstructed using displacement fields that are estimated from sup-images, i.e. images reconstructed from one single data subset. The accuracy of the motion estimation is thus limited by the resolution of the sub-images. In the following, a reconstruction will be described that improves the accuracy of the motion compensation. The basic idea of this technique is reconstruct MC images on an intermediate resolution level that can subsequently be used for more accurate estimate the motion estimation. According to Equation 3, the reconstruction of image on different resolution levels R is described by:

Equation 4:

$$I_{MC}^{R}(\vec{x}) = \sum_i^{N^R} BP\left(\left\{p_\theta\left(\vec{u}_\theta * \left(\vec{x} + \vec{d}_i^R(\vec{x})\right)\right)\right\}_i\right)$$

$$\vec{u}_\theta = (\cos\theta, \sin\theta).$$

The Number N^R of the data subsets $\{p_\theta(\vec{u}_\theta * (\vec{x} + \vec{d}_i^R(\vec{x})))\}_i$ needed to reconstruct an MC image $I_{MC}^R(\vec{x})$ increases with the resolution level R, the displacement $\vec{d}_i^R(\vec{x})$ of each pixel is determined by a motion estimation using images $I_{MC}^{R-1}(\vec{x})$ with lower resolution. In case of acquiring four data subsets MC-images at three resolution levels can be reconstructed as follows: 1) motion estimation is preformed on images reconstructed from the original data subsets with respect to one reference state, e.g. the images have a numerical resolution of 64^2; 2) the estimated motion fields are used to reconstruct an MC-image with a higher intermediate resolution by combining the data of two subsets, e.g. the image has a numerical resolution of 128^2; 3) step 1 and 2 are repeated to reconstruct MC-images with a higher resolution for each motion state e.g. the images have a numerical resolution of 128^2; 4) motion estimation is preformed on the MC-images obtained in step 3, and a hierarchical motion estimation with two levels is applied by refining the motion fields achieved in step 1; and 5) the estimated motion field derived from the MC-images is then used to reconstruct MC-images at the highest resolution level where four subsets have to be combined, e.g. the image has a numerical resolution of 256^2. Due to the fact that the described reconstruction technique generates MC-images of different resolution levels, it can be considered as hierarchical reconstruction improving the accuracy of the motion estimation.